DYNAMICS OF COARSE WOODY DEBRIS IN UNMANAGED PIEDMONT FORESTS AS AFFECTED BY SITE QUALITY

John B. Crooks III, Thomas A. Waldrop, David H. Van Lear, and Victor B. Shelburne[1]

Abstract—Although coarse woody debris (CWD) is accepted as an important component of forest ecosystems, little is known about the changes in CWD loads that might be expected over long periods. This study documents CWD loadings across a chronosequence of 100+-years on three different site types in the piedmont of South Carolina. Seven age classes (0 to 3, 4 to 7, 8 to 15, 16 to 25, 26 to 50, 51 to 100, 100+) and three site types (subxeric, intermediate, and submesic) were sampled on the Clemson Experimental Forest. CWD loads were measured in five stands of each age-site combination using a modified Versiolanar Intersect Method. These data were used to test the FORCAT gap model which was modified to predict CWD accumulation. Field observations showed that CWD loadings varied by age class with smaller amounts found in stands between ages 8 and 25, but the loadings did not vary among landscape ecosystem classification (LEC) units. When comparing FORCAT to field observations, the patterns of CWD loading were similar. However, the model overpredicted CWD loads throughout the simulation period. Predicted CWD loads may have been too high because inputs from harvesting were too high and simulated decomposition rates were too low.

INTRODUCTION

As a forest ecosystem matures and progresses from one successional stage to another, many changes occur. One of these changes is the mortality of trees, which provides coarse woody debris (CWD) to the ecosystem. Nonliving woody material, i.e., any dead fallen or standing tree stem or limb material greater than 3 inches, is called CWD. CWD provides several ecosystem functions such as seed germination sites, reservoirs of moisture during droughts, sites of nutrient exchange for plant uptake, and critical habitat for a number of forest organisms (Harmon 1982, Van Lear 1996, Van Lear and Waldrop 1995). Because of these important functions, CWD should be considered by land managers and incorporated into management regimes. The amount of CWD present on a site may be affected by the type and intensity of silvicultural practices performed on that site.

Although CWD is recognized as an important structural component of forest ecosystems (Harmon and others 1986), little is known about the changes in CWD loads that might be expected over long periods. Most studies in the Southeast have provided short-term "snapshots" of CWD at specific successional stages (MacMillan 1988, Smith and Boring 1990, Muller and Liu 1991). Research on CWD accumulation over time is very limited, with most of it being conducted in the Pacific Northwest (Spies and others 1988, Spies and Cline 1988, Harmon and Hua 1991). However, Hedman and others (1996) have documented loading patterns of CWD by species over a 300+-year chronosequence in Southern Appalachian streams.

Essentially no information is available for long-term CWD dynamics in terrestrial southeastern ecosystems. One study (Waldrop 1996) used the FORCAT gap model (Waldrop and others 1986) to simulate CWD dynamics in mixed-species forests on xeric and mesic sites in east Tennessee. CWD accumulation on the two sites remained relatively low for the first 30 years after clearcutting. From years 30 to 75, there was a rapid increase in CWD accumulation. CWD continued to accumulate after year 75, but at a slower rate, and it reached a maximum at age 90. For the remainder of the 200-year simulation period, decomposition exceeded accumulation and CWD loads gradually decreased. CWD loading on the mesic site decreased much more rapidly than on the xeric site.

The objective of this study was to document CWD accumulation in a chronosequence of selected stands in the piedmont of South Carolina and to examine the effects of stand age and site on CWD accumulation. The results were then used as a rough test to verify the accuracy of the FORCAT CWD model.

METHODS

The study used five replications of a 7*3 factorial arrangement of a completely random design. Factors included stand age (using seven age classes) and site (three site types). Age classes were suggested by the results of Spies and Cline (1988) and Waldrop (1996) and included 0 to 3, 4 to 7, 8 to 15, 16 to 25, 26 to 50, 51 to 100, and over 100 years. All sampled stands in the 100+ age class were between 100 and 125 years of age according to Clemson University records. However, some of these stands were uneven-aged and may have cohorts of trees as old as 175 years. Sites were identified by using the Landscape Ecosystem Classification (LEC) system for the upper piedmont as described by Jones (1991). This system identifies each site type by a combination of soil type, slope position, and aspect. Site types in the upper piedmont include xeric, subxeric, intermediate, submesic, and mesic. In this study, CWD accumulation was measured on subxeric, intermediate, and submesic site types. Differences of CWD accumulation between age classes and site types were detected by analysis of variance (alpha = 0.05) using Duncan's Multiple Range Test for mean separation.

[1] Graduate Research Assistant, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003; Research Forester, USDA Forest Service, Southern Research Station, 239 Lehotsky Hall, Clemson, SC 29634-1003; and Professor and Associate Professor, Department of Forest Resources, Clemson University, Clemson, SC 29634-1003 (respectively).

CWD accumulation was measured in selected stands on the Clemson Experimental Forest in Pickens, Oconee, and Anderson Counties of South Carolina. Sample stands were selected that have similar histories and with little or no management after stand regeneration. Each stand was regenerated (natural or artificial) to pure pine, although—as a result of no management activities—a significant hardwood component was expected in the older stands and on the better sites. Sample stands have no evidence of burning, thinning, herbicide application, or any management activity that would affect natural CWD loadings. Stands to be selected within the younger age classes (0 to 15 years) had no site preparation other than broadcast burning. Although site preparation burning reduces CWD loading to some degree, most of the consumed biomass is smaller than the 3-inch minimum diameter to be considered as CWD (Van Lear 1996). The method of site preparation was not a limitation for selecting sample stands older than 15 years. CWD decomposes rapidly in the Eastern United States and, therefore, CWD loading in stands older than 15 years should not be affected by site preparation technique (Waldrop 1996).

Sample stands for the subxeric, intermediate, and submesic site units were selected by estimating site units on the basis of slope position and aspect (Jones 1991). Once each stand was selected, a more accurate assessment of its site unit classification was made by using methods described by Jones (personal communication). This method uses three measurements to classify site types: soil rating, exposure rating, and terrain surface rating. The soil rating is affected by the depth to the B-horizon and the highest percent clay found in that horizon. The exposure rating is a result of the landform index average of eight clinometer readings from plot center to skylight, and the plot's aspect. Terrain surface rating measures the convexity or concavity of the plot. Measurements in each of these rating areas are taken on each plot, and values from 0 to 10 are assigned in each area with low values associated with mesic indicators and high values associated with xeric indicators. The three values are then summed to produce an environmental score which identifies the plot along an environmental gradient from mesic to xeric. All 105 sample plots were therefore evaluated and assigned a site unit from mesic to xeric.

One sample plot was randomly placed in each stand. Sample plots were square and 1/10 acre in size. Each side was 66 feet long. The corners and the plot center were marked with flags at each point. CWD accumulation in each sample plot was measured by the planar intersect method (Brown 1974). This technique was developed for conditions in the Western United States, but it was adapted for sites on the Clemson Experimental Forest by Sanders and Van Lear (1988). Five 50-foot-long planar transects were located within each 1/10-acre sample plot, one on each side and one along the diagonal between the fourth and second corners.

The diameter and decomposition stage (Maser and others 1979) of each piece of woody material that crossed the plane defined by the 50-foot transect was measured and recorded. The diameter of pieces of CWD larger than 1.0 inch was measured and recorded along the entire 50-foot transect. CWD that was less than 1.0 inch in diameter was measured for only the first 15 feet of the 50-foot transect. It was assumed that all CWD lies in a horizontal plane. A correction factor was used for slopes over 10 percent (Brown 1974). These CWD data were converted to biomass to produce an estimate of total amount of CWD loading.

If any snags were present in the plot, their diameter, decay class, and species type (pine or hardwood) were recorded. The condition of each snag was determined by placing it into one of five different decay classes (Maser and others 1979), where Class I is a recently dead tree and Class V is a stump with little woody material remaining. These data were then entered into diameter regression equations obtained from Clark and others (1986) and Van Lear and others (1984) to produce biomass values.

RESULTS AND DISCUSSION

A total of 105 stands (seven age classes * three site types * five replications) was selected for this study. Because of the strict criteria placed on stand selection, only 82 of these sample stands were found on the Clemson Experimental Forest. The number of sample stands was evenly distributed across age classes and site units, except for the 4 to 7 age class which had only four plots (table 1). Because the sample size for the 4- to 7-year age class was too small, these plots were excluded from the study. Therefore, this study uses only 6 age classes and a total of 78 sample plots.

Figure 1 shows loadings of CWD for each site unit within each age class. CWD loading of the 1- to 3-year age class is very high, due to logging slash left from clearcutting the previous stand. This slash decomposes very rapidly and the loading decreases to a minimum somewhere between 8 and 25 years of age. CWD loading began to increase in 16- to 25-year-old stands, probably due to canopy closure and increased mortality. This increase in loading is seen throughout the final three age classes, reaching a peak in

Table 1—Number of sample plots by age class and landscape ecosystem classification unit

	Landscape ecosystem classification unit		
Age class	Subxeric	Intermediate	Submesic
Years			
0 to 3	5	5	2
4 to 7	1	2	1
8 to 15	5	5	3
16 to 25	5	5	4
26 to 50	3	5	3
51 to 100	5	5	5
100+	4	4	5

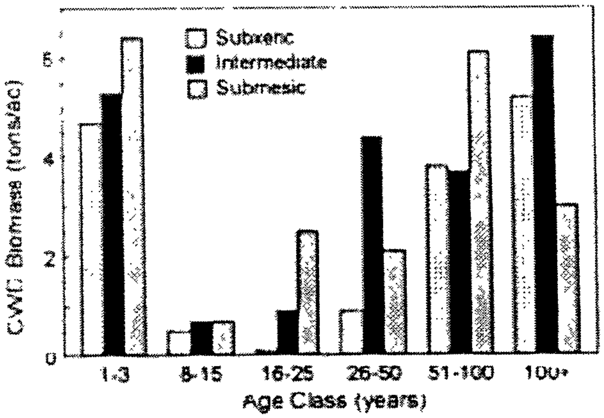

Figure 1—Coarse woody debris accumulation by age class and landscape ecosystem classification unit.

the 100+ age class. Analysis of variance showed that the loadings of the 8 to 15 and 16 to 25 age classes were significantly lower (F= 5.05, P= 0.0006) than those of the other four age classes, suggesting that CWD loadings do vary with stand age.

Differences in CWD loadings among LEC units were compared across the age classes. We expected that submesic sites would have the highest CWD loading, due to higher site productivity, and that subxeric sites would have the lowest. This expected trend held true for the first three age classes, but not for all six. A possible explanation for this trend is the different rates of succession that occur among LEC units. Because these stands are unmanaged, species composition changes over time. This change could alter the physical characteristics of the stand, the amount of debris accumulating on the site, and the decomposition rates of the debris. CWD loading may be higher on the more productive sites immediately after disturbance. However, after these periodic heavy loads decompose, the relatively high inputs on productive sites may be balanced by faster decomposition rates.

One of the objectives of this study was to use these field observations as a validation for the FORCAT model. To make a more equal comparison between the two studies, only the subxeric site field observations were used because the FORCAT model simulated loadings on xeric sites. When these two graphs (fig. 2) were compared, there were both similarities and differences. The two curves had the same general pattern of CWD loading over time. Both had a U-shaped pattern for the first half of the time period and a bell-shaped curve for the remainder. The major difference in the two curves is that the magnitude of CWD loading in the FORCAT predictions was greater than that of the field observations. This could be due to the differences in the locations of the two study sites. Since the FORCAT simulations were based on conditions of the Cumberland Plateau of east Tennessee and the field observations were obtained from the piedmont of South Carolina, differences in soil, topography, elevation, and species composition may affect the amount of CWD accumulating on the sites.

The differences in the magnitude of CWD loading could also be caused by an overestimation of the biomass of postharvest slash made by the FORCAT model. To test this possibility, field measurements from a fuel loading study (Scholl 1996) on sites in South Carolina were substituted for those estimated by FORCAT. The result (fig. 3) was that loadings became very similar to the observed field measurements of this study for the first few years after harvest. Therefore, the FORCAT model seems to overestimate postharvest CWD loadings and the need for modifications is indicated.

When comparing the two curves as in figure 2, their minimums are somewhat different. The FORCAT model predicts the minimum about 10 years later than the actual field observations. This difference may indicate that the decomposition rates of the model were too low. If the decomposition rates were too low, then the debris would be on the site longer; therefore, shifting the curve to the right. To test for this assumption, the simulated decomposition rate was increased from 6 percent to 12 percent. With this adjustment, the two curves (fig. 3) become very similar throughout the simulation period. A 12 percent decomposition rate may be unrealistically high for subxeric

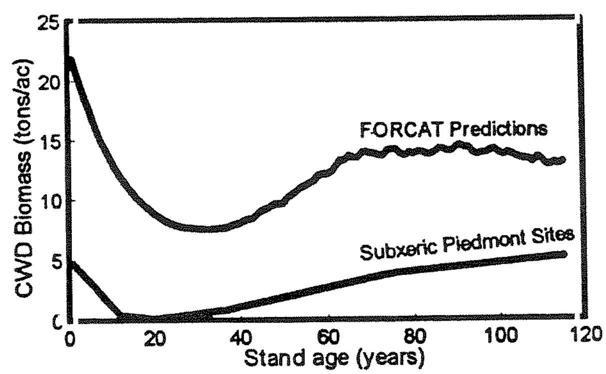

Figure 2—Comparison of coarse woody debris loadings between FORCAT predictions (using a 6 percent decomposition rate) and subxeric piedmont sites.

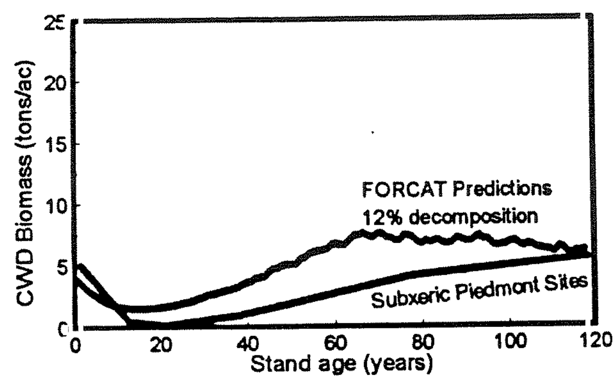

Figure 3—FORCAT loading predictions adjusted to a 12 percent decomposition rate and compared to subxeric piedmont sites.

sites, but its use here for preliminary model testing emphasizes the ability of FORCAT to predict the pattern of CWD loading.

A limitation to the FORCAT simulation study was the lack of accurate mortality and decomposition rates for each species and site type. Since the FORCAT model was tailored for a specific area and not verified by field observations, adjustments would have to be made so that it could be used for other areas. If a database of site characteristics and conditions could be established for a range of site units in different geographic areas, this model could then be adjusted to accurately represent CWD loadings on a wide array of sites.

CONCLUSIONS

For piedmont sites in South Carolina, observed field observations showed that the loading of CWD varied by age class with smaller amounts found in stands between ages 8 and 25. Consequently, these CWD loadings did not vary among LEC units. The pattern of CWD accumulation over time within the study stands was similar to a chronosequence reported by Spies and Cline (1988) and model predictions reported by Waldrop (1996).

When looking at the comparison between the FORCAT model projections and this study's observed field observations, it is seen that the FORCAT model successfully predicts the patterns of CWD accumulation over time, but it overpredicts the postharvest CWD levels after clearcutting. Also, FORCAT predicted the magnitude of CWD loading to be somewhat higher than the field observations. These predictions may have been too high because simulated decomposition rates were too low.

This study is only a preliminary validation for the FORCAT model. The model is not ready to be used immediately as a management tool, but this study does show that there is potential for its use in the future. The key to the model's success is that more research has to be conducted in the areas of decomposition rates and CWD inputs over time for various site types. If a database could be established that incorporates various site characteristics for different geographic areas, models such as FORCAT could be adjusted to compensate for these variables. This would then enable land managers to use these model projections to help determine how to alter the level or timing of their activities to enhance CWD loading on both a stand and a landscape scale.

LITERATURE CITED

Brown, J.K. 1974. A planar intersect method for sampling fuel volume and surface area. Forest Science. 17:96-102.

Clark, Alexander, III; Phillips, Douglas R.; Frederick, Douglas J. 1986. Weight, volume, and physical properties of major hardwood species in the Upland-South. Res. Pap. SE-257. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 55 p.

Harmon, Mark E. 1982. Decomposition of standing dead trees in the Southern Appalachian Mountains. Oecologia. 52:214-215.

Harmon, M.E.; Franklin, J.F.; Swanson, F.J. [and others]. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research. 15:133-302.

Harmon, M.E.; Hua, C. 1991. Coarse woody debris dynamics in two old-growth ecosystems. Bioscience. 41:604-610.

Hedman, Craig W.; Van Lear, David H.; Swank, Wayne T. 1996. In-stream large woody debris loading and riparian forest seral stage associations in the Southern Appalachian Mountains. Canadian Journal of Forest Research. 26(7):1218-1227.

Jones, S.M. 1991. Landscape ecosystem classification for South Carolina. In: Mengel, D.L.; Tew, D.T., eds. Ecological land classification: applications to identify the productive potential of southern forests. Proceedings of a symposium; 1991 January 7-9; Charlotte, NC. Gen. Tech. Rep. SE-68. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 59-68.

MacMillan, P.C. 1988. Decomposition of CWD in an old-growth Indiana forest. Canadian Journal of Forest Research. 18(11):1353- 1362.

Maser, C.; Anderson, R.G.; Cromack, K., Jr. [and others]. 1979. Dead and down woody material. In: Thomas, J.W., tech. ed. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture: 78-95.

Muller, R.N.; Liu, Yan. 1991. Coarse woody debris in an old-growth deciduous forest on the Cumberland Plateau, southeastern Kentucky. Canadian Journal of Forest Research. 21:1567-1572.

Sanders, B.M.; Van Lear, D.H. 1988. Photos for estimating residual loadings before and after burning in Southern Appalachian mixed pine-hardwood clearcuts.Gen. Tech. Rep. SE-49. U.S. Department of Agriculture, Forest Service. 21 p.

Scholl, Eric. 1996. Fuel classification for prescribed burning of longleaf and loblolly pine plantations in the Upper Coastal Plain. Clemson University, Clemson, SC. 62 p. M.S. thesis.

Smith, R.N.; Boring, L.R. 1990. *Pinus rigida* coarse woody debris inputs and decomposition in pine beetle gaps of the Southern Appalachians. Bulletin of the Ecological Society of America, program and abstracts, 75th annual ESA meeting; 1990 July 29-August 2; Snowbird, Utah. Supplement to vol. 71, No.2. Tempe, AZ: The Ecological Society of America: 329.

Spies, T.A.; Cline, S.P. 1988. Coarse woody debris in forest and plantations of Coastal Oregon. Chapter 1. In: Maser, C.; Tarrant, R.F.; Trappe, J.M.; Franklin, J.F., tech. eds. From the forest to the sea: a story of fallen trees. Gen. Tech. Rep. PNW-GTR-229. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Spies, T.A.; Franklin, J.F.; Thomas, T.B. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. Ecology. 69(6):1689-1712.

Van Lear, David H. 1996. Dynamics of coarse woody debris in southern forest ecosystems. In: McMinn, James W.; Crossley, D.A., Jr., eds. Biodiversity and coarse woody debris in southern forests, proceedings of the workshop on coarse woody debris in southern forests: effects on biodiversity; 1993 October 18-20; Athens, GA. Gen. Tech. Rep. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 146 p.

Van Lear, David H.; Waide, J.B.; Teuke, M.J. 1984. Biomass and nutrient content of a 41-year-old loblolly pine (*Pinus taeda* L.) plantation on a poor site in South Carolina. Forest Science. 30(2):395-404.

Van Lear, David H.; Waldrop, Thomas A. 1995. Coarse woody debris considerations in southern silviculture. In: Edwards, M. Boyd, comp. Proceedings of the eighth biennial southern silvicultural research conference; 1994 November 1-3; Auburn, AL. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 633 p.

Waldrop, Thomas A. 1996. Dynamics of coarse woody debris—a simulation study for two southeastern forest ecosystems. In: McMinn, James W.; Crossley, D.A., Jr., eds. Biodiversity and coarse woody debris in southern forests, proceedings of the workshop on coarse woody debris in southern forests: effects on biodiversity; 1993 October 18-20; Athens, GA. Gen. Tech. Rep. SE-94. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 146 p.

Waldrop, T.A.; Buckner, E.R.; Shugart, H.H., Jr.; McGee, C.E. 1986. FORCAT: A single tree model of stand development following clearcutting on the Cumberland Plateau. Forest Science. 32(2):297-319.